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# Effects of Radio Channel on Networking Performance

## Outputs

- Quantitative analysis of effects of radio channel on network performance.
- Bit, frame, and packet error wait time statistics.

The Institute is a recognized leader in radio channel measurement and modeling. Such knowledge is essential in the development of new, spectrally efficient radios which will operate in radio channels degraded by multipath, man-made noise, and interference. This is especially true for the mobile radio channel whose degradations vary with time. For example, development of new adaptive equalizers for modern, wide-bandwidth mobile radios would not be possible without radio channel measurement and modeling.

Systems using mobile radios to access the Internet are proliferating. IEEE 802.11 "Wi-Fi" wireless local area network (WLAN) and personal communications services (PCS) general packet radio service (GPRS) are but two examples. To reach their fullest potential these systems must reach large numbers of people and have correspondingly high bandwidth efficiencies per unit area, i.e., spectrum efficiency. In the past, enormous gains in spectrum efficiency have

been found through advances in cellular frequency reuse and multiple access methodologies. In the future, equally significant gains may be found in novel queuing, routing, and retransmission algorithms.

These gains are unlikely to be realized without knowledge of the radio channel obtained through radio channel measurement and modeling. Currently, the Institute is promoting the use of this knowledge in two ways. First, it is conducting a comprehensive literature search to determine the scope of the effects of the mobile radio channel on networking tasks. Thus far, the literature search indicates that networking tasks are as sensitive to second-order statistics such as the distribution of wait time between packet errors as they are to the commonly studied first-order statistics such as packet error rate. Second, the Institute is developing methods for extracting these statistics from radio channel measurements and models.

The Gaussian Wide Sense Stationary Uncorrelated Scattering channel presented by Hufford\* is often used to model the mobile radio channel. This model describes archetypal regions, i.e., urban and in-

building regions, with statistically varying direct-path and multipath components. The multipath component is composed of an exponentially decaying continuum of indirect paths characterized by strength (relative to the direct component) and time constant parameters. Figure 1 shows a single realization or "snapshot" of the impulse response amplitude from an urban mobile radio channel where the strength and time constants are -5 dB and 0.5 microseconds, respectively.

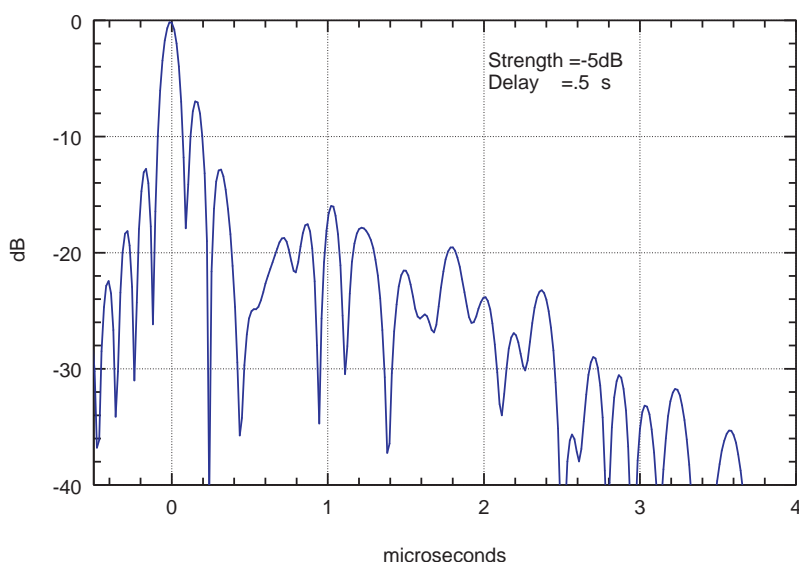


Figure 1. Radio channel impulse response amplitude.

\*G. Hufford, "A characterization of the multipath in the HDTV channel," *IEEE Trans. on Broadcasting*, vol. 38, no. 4, pp. 252-255, Dec. 1992.

It was theorized that independent and identically distributed bits transmitted over this channel would result in exponentially distributed wait times between bit errors. This hypothesis is confirmed by simulations. As an example, Figure 2 shows the complementary cumulative distribution of the wait times between bit errors which were determined from simulations of a binary phase shift keyed (BPSK) signal transmitted at 6 million bits per second at a 0.0043 bit error rate.

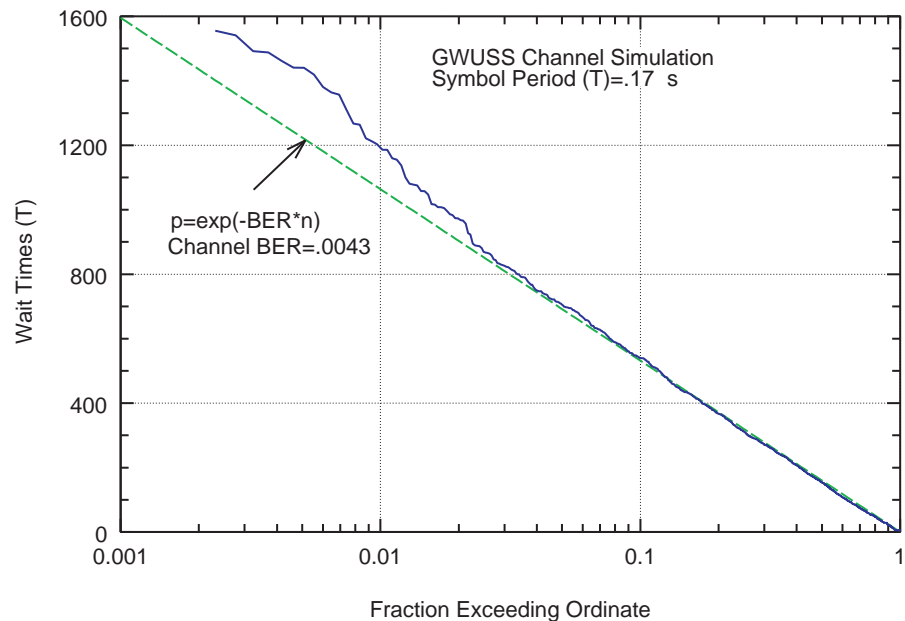


Figure 2. Complementary cumulative distribution function of bit error wait times for radio channel depicted in Figure 1.

The distribution is plotted on a log-linear graph where an exponentially distributed random variable is displayed as a negatively sloped line. The ordinate is the wait time between bit errors in units of symbol periods. The abscissa is the fraction of time the ordinate is exceeded. The mean wait time is the inverse of the bit error rate or 232.5 symbol periods. The graph shows that the wait time between bit errors exceeds 1071, 535, and 161 symbol periods for 1, 10, and 50 percent of the time, respectively.

Packet wait times are also exponentially distributed. For the above example, a packet 207 bytes long, 20 of which are error correction bytes capable of correcting 10 byte errors, would be transmitted at a rate of 3623 packets per second. The corresponding byte and packet error rates are 0.034 and 0.1, respectively. The mean wait time between packet errors is the inverse of the packet error rate or 10 packet periods. Wait time between packet errors exceeds 46, 23, and 7 packet periods for 1, 10, and 50 percent of the time, respectively.

Results such as these are immediately useful to network designers. For example, since the packet error rate is high, the network designer may ask for a lower BER, drop queued packets from this link first when switches are congested, reroute packets away from this link if possible, or deny retransmission of packets from this link.

Ultimately, results such as these will benefit the public and private sectors by facilitating the integration of new wireless links into existing legacy networks, reducing the proliferation of redundant wireless network protocols, and decreasing the pressure for additional spectrum by using existing allocations more efficiently. These benefits will become more meaningful as the convergence of voice and data as well as fixed and mobile users onto the Internet continues.

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